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EVIDENCE FOR BEAMED ELECTRONS IN A LIMB X-RAY FLARE OBSERVED BY HXIS

Eberhard Haug and Gerhard Elwert

Lehrstuhl für Theoretische Astrophysik
Universität Tübingen, F.R.G.

The limb flare of 1980 November 18, 14:51 UT, was investigated on the basis of X-ray images taken by the Hard X-ray Imaging Spectrometer (HXIS) and of X-ray spectra from the Hard X-Ray Burst Spectrometer (HXRBS) aboard SMM. The impulsive burst was also recorded at microwave frequencies between 2 and 20 GHz whereas no optical flare and no radio event at frequencies below 1 GHz was reported. The flare occurred directly at the SW limb of the solar disk; this fact allows to study the height variation of the X-ray emission. During the impulsive phase several X-ray bursts of short duration (elementary flare bursts) were recorded by HXRBS at energies between 29 and ~300 keV (Fig.1) and by the high-energy bands of HXIS (16 - 30 keV).

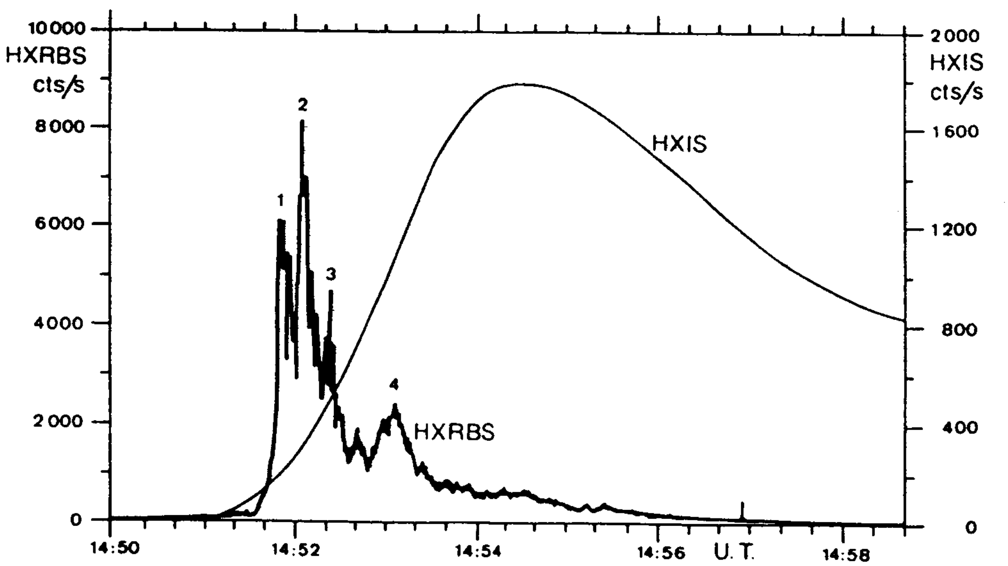

Fig. 1. Time evolution of the soft and hard X-radiation as observed by HXIS and HXRBS, respectively.

Deconvolved contour maps of the flare site (Fig.2) show that during the short-term spikes the 22 - 30 keV radiation is mainly emitted from a compact area close to the solar limb. In contrast, the source of the last major X-ray spike which has a longer duration of about 15 sec and a softer

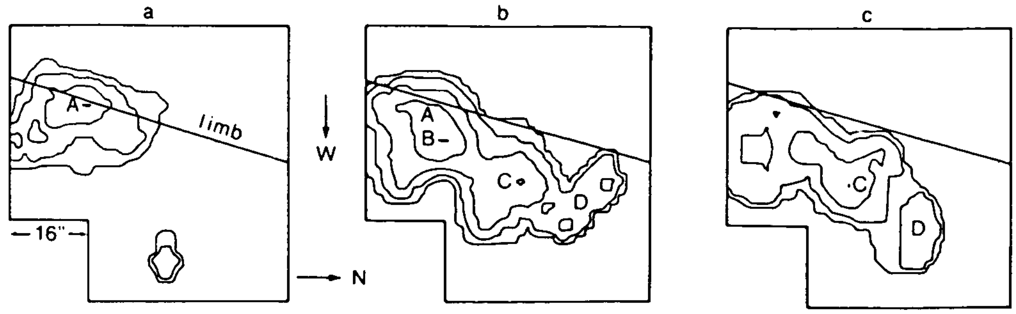

Fig. 2. 22–30 keV contour maps of the flare region for the time periods (a) 14:51:37–14:51:58, (b) 14:52:45–14:53:05, and (c) 14:53:10–14:53:33. The contour levels correspond to 100, 50, 25, 12.5, and 6.25% of the peak counting rate.

spectrum is situated at greater heights in the solar atmosphere. The hard X-ray light curves of the short-time bursts are in very good agreement with the microwave time profiles whereas the broader X-ray spike is missing in microwaves.

Taking advantage of the spatial resolution of the HXIS images (8" corresponding to ~6000 km on the Sun), the time evolution of the X-radiation originating from relatively small source regions can be studied (Fig.3). In particular, the elementary flare bursts which are observed by HXRBS without spatial resolution may be attributed to different source regions.

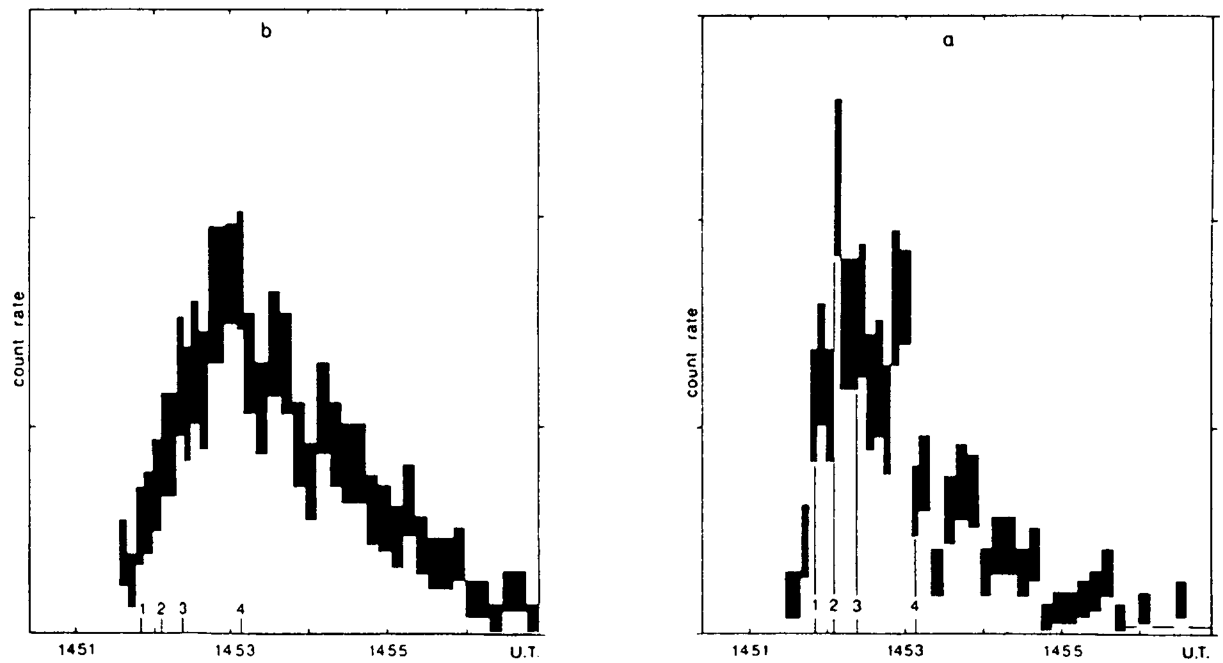

Fig. 3. Time evolution of the 22-30 keV count rates in areas A (a) and B (b). The marks on the abscissae denote the maxima of the corresponding hard X-ray spikes of Figure 1.

During the impulsive phase of the flare the hard X-ray spectra generally could be well fitted to a power law with spectral index γ (Fig.4). Using the HXIS count rates of individual pixels it is possible to determine the spectra of X-rays originating from different source regions. Particularly, in limb flares the height variation of spectra measured simultaneously can be studied. This was performed for the regions around the compact source of the short-term X-ray spikes. During these bursts the spectra are quite hard (γ = 3.2 to 4) and there is a systematic trend of the spectral index γ to increase with increasing height of the source above the solar limb.

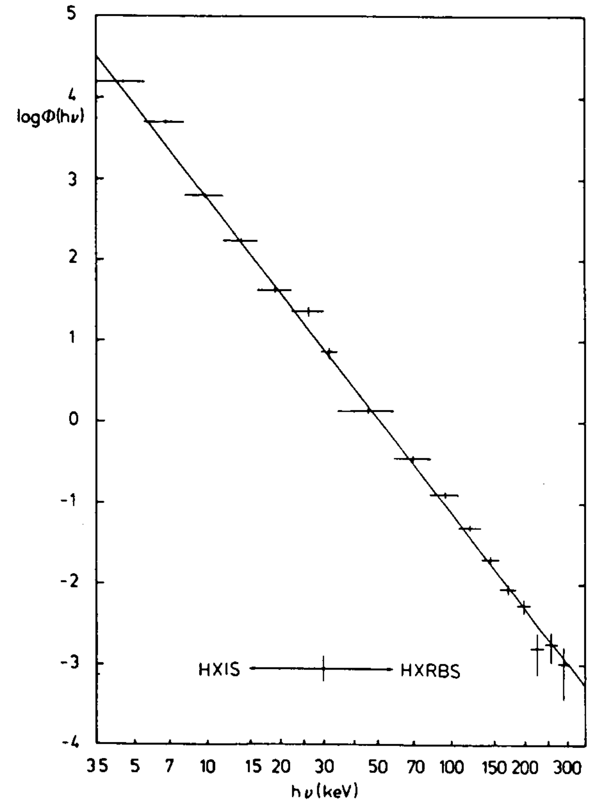

Fig. 4. Composite HXIS and HXRBS spectrum (X-ray flux $\Phi(h\nu)$ in units of $cm^{-2}s^{-1}keV^{-1}$) taken during the first hard X-ray spike around 14:51:56. The straight line represents the best fit to a power law with spectral index γ = 3.88.

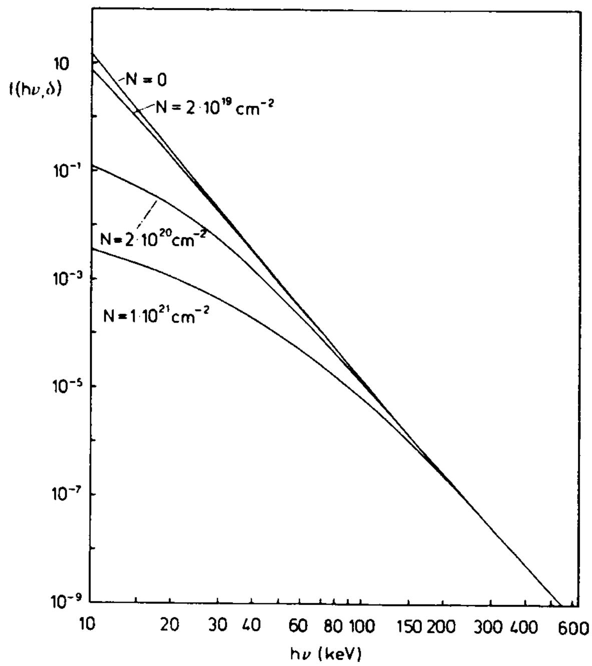

Fig. 5. Theoretical variation of X-ray spectra, produced by electrons injected with a power-law energy distribution, with increasing column density traversed, N. The electron spectral index is δ = 5, and the ordinate scale is in arbitray units.

Using Monte Carlo computations of the energy distribution of energetic electrons traversing the solar plasma, the bremsstrahlung spectra produced by these electrons have been derived (Haug et al., 1985). Under the assumption that the electrons are injected at high altitudes in the corona, e.g., at the top of a magnetic loop, with a power-law spectrum in kinetic energy, the resulting X-ray spectra are hardest at high column densities of the

plasma traversed by the electrons, i.e., at low altitudes (Fig.5). This is a consequence of the more rapid slowing down of the less energetic electrons due to Coulomb collisions. The observed hardening of the X-ray spectra with decreasing altitude of the X-ray source is consistent with the existence of nonthermal electron beams precipitating from the corona toward the dense layers of the solar atmosphere. The compact X-ray source situated close to the solar surface can be interpreted as the footpoint of a flaring loop; the other footpoint is occulted by the solar disk. This interpretation is also in accordance with the fact that after the short-term spikes the differences between the γ values of regions at various altitudes have decreased considerably. Moreover, the spectra have softened. These characteristics indicate that the injection of electrons has ceased and that the energetic particles have thermalized.

A full account of this work has been given in Solar Physics 99, 219 (1985).

Reference

Haug, E., Elwert, G., and Rausaria, R.R. 1985, Astron. Astrophys. 146, 159.